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FRAMING THE SOCIAL, POLITICAL, AND ENVIRONMENTAL RISKS AND BENEFITS OF GEOENGINEERING: BALANCING THE HARD-TO-IMAGINE AGAINST THE HARD-TO-MEASURE

Gareth Davies*

INTRODUCTION

In recent decades a number of scientists and writers have suggested techniques which could be used to lower the temperature of the earth and thereby counteract man-made global warming.¹ Such techniques are commonly called geoengineering: engineering the earth.²

The proposals have attracted a range of reactions. Environmental groups have generally been hostile, seeing geoengineering as a dangerous distraction from the only real solution — reducing emissions. Geoengineering has been described as treating the symptoms, not the cause. Scientific and academic writers have been less definite, with the most common standpoint, almost a consensus, being that geoengineering may be necessary as a last resort if dangerous climate tipping points approach, but that, because of its risks, everything should be done to avoid this situation.³ Emissions reduction, almost all writers agree, is far preferable. Insofar as there is any enthusiasm for geoengineering, it is largely based on pessimism that such reduction will actually occur and a perception that geoengineering is a lesser evil than unfettered warming. Only a very few writers take the more radical position that geoengineering may be a first choice,

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1. See ROYAL SOC'Y, GEOENGINEERING THE CLIMATE: SCIENCE, GOVERNANCE AND UNCERTAINTY (2009); Alan Carlin, *Global Climate Change Control: Is There a Better Strategy Than Reducing Greenhouse Gas Emission?*, 155 U. PA. L. REV. 1401, 1403-04 (2007); T.M.Lenton & N.E.Vaughan, *The Radiative Forcing Potential of Different Climate Geoengineering Options*, 9 ATMOSPHERIC CHEMISTRY & PHYSICS 5539, 5546-53 (2009); Stephen H. Schneider, *Geoengineering: Could We or Should We Make It Work?*, 366 PHIL. TRANSACTIONS ROYAL SOC'Y A 3843, 3847 (2008), available at <http://www.rsta.royalsocietypublishing.org/content/366/1882/3843.full.pdf+html>.

2. The term is usually traced back to Marchetti. Research Memorandum from Cesare Marchetti on Geoengineering and the CO₂ Problem to the Int'l Inst. for Applied Sys. Analysis (Mar. 1976) (on file with the University of Tulsa College of Law).

3. See ROYAL SOC'Y, *supra* note 1, at ix; Peter G. Brewer, *Evaluating a Technological Fix for Climate*, 104 PROC. NAT'L ACAD. SCI. U.S. 9915, 9916 (2007); Paul J. Crutzen, *Albedo Enhancement by Stratospheric Sulfur Injections: A Contribution to Resolve a Policy Dilemma?*, 77 CLIMATIC CHANGE 211, 217 (2006); Schneider, *supra* note 1, at 3855; John Virgoe, *International Governance of a Possible Geoengineering Intervention to Combat Climate Change*, 95 CLIMATIC CHANGE 103, 106 (2008).

not a second.⁴ They argue that it is cheap, and need not be dangerous, and so permits protection of the environment alongside the economic and development benefits of carbon fuel use.

This paper challenges that “lesser evil” consensus.⁵ It may be that geoengineering is undesirable, and only desirable as a last resort. But it may also be that it could make a useful contribution to an optimal welfare outcome for humanity. One cannot take a firm position on the basis of the current limited research. Thus it is not yet possible to argue that geoengineering is part of the solution to climate change, but the widespread assumption that it is relatively undesirable is without basis too.

That assumption matters because it influences the research and policy priority accorded to geoengineering techniques. There are many voices suggesting that research should proceed cautiously, that geoengineering should not yet be considered as a possible policy option, and that public and intellectual engagement in general should be avoided, or deferred. Partly this is because of the fear of deterring mitigation, mentioned above, but there are also more complex political and ideological issues involved. In offering a technical solution to a global problem, geoengineering would threaten established ways of thinking about nature, sustainability, and social progress. This is discussed below in part five.

The paper proceeds in several steps. Parts two and three describe and present the various kinds of geoengineering techniques that have been proposed. Part four then considers the kind of risk-benefit framework that is necessary to evaluate them. Part five considers the kinds of factors that would need to be weighed within that framework: environmental, economic, governance, and social. Part six concludes.

THE RANGE OF GEOENGINEERING OPTIONS

Any standpoint on the desirability of geoengineering depends, at least to some extent, on the type of geoengineering under consideration. The range of proposals is considerable, and the possible risks and benefits vary too. Some are apparently safe but seem on the basis of research so far to be expensive and ineffective. Others are argued to be cheap and effective but bring very considerable, and very uncertain, risks.⁶

The techniques proposed can be broadly divided into two groups, following the practice adopted by the Royal Society in its very comprehensive 2009 report *Geoengineering the Climate*.⁷ The first proposals, comprising the first group, aim at

4. See, e.g., David W. Keith, *Engineering the Planet*, in CLIMATE CHANGE SCIENCE AND POLICY 494, 494 (Stephen Schneider et al. eds., 2010); WILLIAM NORDHAUS, A QUESTION OF BALANCE: WEIGHING THE OPTIONS ON GLOBAL WARMING POLICIES 78-79 (2008); WILLIAM D. NORDHAUS & JOSEPH BOYER, WARMING THE WORLD: ECONOMIC MODELS OF GLOBAL WARMING 126-32 (2000); Deepak Lal, *Eco-Fundamentalism*, 71 INT'L AFF. 515, 520 (1995); Edward Teller et al., *Active Climate Stabilization: Practical Physics-Based Approaches to Prevention of Climate Change*, LAWRENCE LIVERMORE NAT'L LABORATORY, Apr. 18, 2002, at 1, 4, available at <http://www.osti.gov/accomplishments/documents/fullText/ACC0233.pdf>.

5. The phrase is taken from Stephen M. Gardiner, *Is “Arming the Future” with Geoengineering Really the Lesser Evil?*, in CLIMATE ETHICS 284, 284 (Stephen M. Gardiner et al. eds., 2010). See also STUART HAMPSHIRE, MORALITY AND PESSIMISM 16 (1972); Steven Kelman, *Cost-Benefit Analysis: An Ethical Critique*, AEI J. ON GOV'T & SOC'Y REG., Jan./Feb. 1981, at 33, 34, available at http://fiesta.bren.ucsb.edu/~costello/courses/ESM204/ESM204_2007/Readings/CBAEthicalCritique.pdf.

6. See ROYAL SOC'Y, *supra* note 1, at 6.

7. *Id.* at 1.

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capturing carbon from the atmosphere and have been named Carbon Dioxide Removal (“CDR”) techniques. These include planting lots of trees, creating artificial trees which absorb CO₂, putting iron in the oceans to stimulate CO₂ uptake by algae, and fitting CO₂ absorbers to power stations. As can be seen, many of these techniques are not very scary. In general, it is hard to imagine that their climatic effects will be disastrous, since they aim merely to undo what mankind is doing by emitting CO₂. Side effects are sometimes a cause for concern, as is the case with iron fertilization of the seas, but for the majority of the techniques, which simply absorb CO₂ by one means or another, this is generally regarded as a non-issue — although whether that is entirely supported by evidence will be returned to below.

In most cases, therefore, criticism of CDR methods focuses on cost, effectiveness, and whether they amount to a distraction from the important task of emissions reduction. The particular strength of most CDR measures is that they promise to return the atmosphere to what it was, with all the associated images of naturalness, conservation, and safety. The particular weakness of CDR measures is that most research suggests that they would require very heavy investment for relatively low returns.⁸ Realistically, it would not be possible to put up enough natural or artificial trees to deal with all the CO₂ we emit, and recent research on ocean fertilization has been disappointing too.⁹ At best, CDR techniques may be used alongside emissions reductions as part of an overall package,¹⁰ but even then critics point out the relatively high costs which CDR techniques seem, on the basis of current research, to involve.

The other major group of proposals aims to cool the earth by increasing its albedo — the degree to which it reflects sunlight. These Solar Radiation Management (“SRM”) techniques ignore the amount of CO₂ in the atmosphere and focus exclusively on reflecting away heat. In general, it appears that an increase of a few percent in the amount of sunlight reflected, rather than absorbed, would reduce global temperature by several degrees.¹¹ It appears, moreover, that there are various ways in which such an albedo increase could be produced.¹² Some of these ways have a slightly sci-fi aura to them, such as proposals to place billions of tiny mirrors in space between the earth and the sun.

However, there are two which stand out for being apparently practical and technologically straightforward. One of these is an increase in the reflectivity of cloud cover. It has been argued that, at a cost of merely billions, or at most tens of billions, per year, a fleet of around 1500 wind-powered ships could spray sea water in the air and the result would be a slight change in the composition of clouds, with the result that they would reflect enough extra light to entirely undo man-made global temperature increase.¹³ This is a fairly dramatic claim, since it promises to end global warming in a

8. *Id.* at 21.

9. *Id.* at 17; Lenton & Vaughan, *supra* note 1, at 5540.

10. Cf. T.M.L. Wigley, *A Combined Mitigation/Geoengineering Approach to Climate Stabilization*, 314 *SCIENCE* 452 (2006).

11. ROYAL SOC’Y, *supra* note 1, at 24.

12. *Id.* at 25.

13. *Id.* at 27; John Latham et al., *Global Temperature Stabilization Via Controlled Albedo Enhancement of Low-Level Maritime Clouds*, 366 *PHIL. TRANSACTIONS ROYAL SOC’Y A* 3969, 3970 (2008), available at

simple and cheap way. However, there have been doubts about the effectiveness of the technique,¹⁴ and there is not yet any scientific consensus regarding the point, with the result that cloud albedo enhancement has, in recent years, taken second place in the pantheon of proposals. The current poster child is, rather, the insertion of sulphur particles into the stratosphere.¹⁵ This high-flying powder would then reflect sufficient sunlight to compensate for the warming effects of the CO₂ in the atmosphere below.

This idea was discussed influentially in 2006 by the Nobel Prize winner, Paul Crutzen, and it appears that a sufficient amount of sulphur to return the global temperature to its pre-global-warming state could be inserted by a number of simple and cheap techniques.¹⁶ Perhaps most strikingly, it has been suggested that simply adding a bit of sulphur to jet fuel — making it a bit dirtier — could combat global warming, an idea which is both poetic and ironic, if not widely accepted.¹⁷ Nevertheless, it does seem relatively accepted that the sulphur could be delivered and maintained without too much difficulty; for example, by fitting ordinary jet aircraft with appropriate tanks. The Royal Society adopted Robock's calculation that nine (yes nine!) jet aircraft could deliver sufficient sulphur to cease global temperature rise. (Robock suggests using military refueling craft because of their tank capacity.)¹⁸

The reasons why sulphur in the stratosphere is becoming the geoengineering technique of choice among aficionados are several. First, it appears to be cheap. There is broad consensus that the cost of such addition would be in the order of billions or tens of billions of dollars or euros per year.¹⁹ To put this cost in perspective, it is suggested that, for between one and thirty dollars per person in the developed world, the entire warming effects of CO₂ could be eliminated. This has been understandably described as "incredible" and would cost less, by an order of magnitude, than many other techniques, or than the several hundreds of billions per year which have been (controversially) attributed to emissions reduction.²⁰ There are a number of question marks surrounding both the costs and the comparison with emissions reduction, which are returned to below,

<http://rsta.royalsocietypublishing.org/content/366/1882/3969.full>; Stephen Salter et al., *Sea-Going Hardware for the Cloud Albedo Method of Reversing Global Warming*, 366 PHIL. TRANSACTIONS ROYAL SOC'Y A 3989, 3990 (2008), available at <http://www.rsta.royalsocietypublishing.org/-content/366/1882/3989.full.pdf+html>.

14. ROYAL SOC'Y, *supra* note 1, at 28; Lenton & Vaughan, *supra* note 1, at 5548.

15. Brewer, *supra* note 3, at 9915; Lenton & Vaughan, *supra* note 1, at 5548.

16. Crutzen, *supra* note 3, at 212; Lenton & Vaughan, *supra* note 1, at 5556; Wigley, *supra* note 10.

17. PANEL ON POLICY IMPLICATIONS OF GREENHOUSE WARMING, POLICY IMPLICATIONS OF GREENHOUSE WARMING: MITIGATION, ADAPTATION, AND THE SCIENCE BASE 453 (1992) [hereinafter PANEL].

18. ROYAL SOC'Y, *supra* note 1, at 32. See also Alan Robock et al., *Benefits, Risks, and Costs of Stratospheric Geoengineering*, 36 GEOPHYSICAL RES. LETTERS L19703 (2009). C.f. Philip J. Rasch et al., *An Overview of Geoengineering of Climate Using Stratospheric Sulphate Aerosols*, 366 PHIL. TRANSACTIONS ROYAL SOC'Y A 4007 (2008).

19. PANEL, *supra* note 17, at 453; ROYAL SOC'Y, *supra* note 1, at 3; Dan Bradley, *Geoengineering Research*, POSTNOTE, Mar. 2009, at 1, 3; Crutzen, *supra* note 3, at 32; Keith, *supra* note 4, at 495-96; Lenton & Vaughan, *supra* note 1, at 5555; Robock et al., *supra* note 18, at 2-4.

20. Scott Barrett, *The Incredible Economics of Geoengineering*, 39 ENVTL. RESOURCE ECON. 45 (2008), available at <http://www.sais-jhu.edu/bin/w/p/Geoengineering.pdf>. See also NICHOLAS STERN, THE ECONOMICS OF CLIMATE CHANGE: THE STERN REVIEW 267 (2007). The Intergovernmental Panel on Climate Change estimates mitigation costs far lower, at around fifty billion dollars per year (0.12% of global GDP), little more than the geoengineering estimates. Terry Barker & Igor Bashmakov, *Mitigation from a Cross-Sectoral Perspective*, in CLIMATE CHANGE 2007: MITIGATION OF CLIMATE CHANGE 621-87 (Bert Metz et al. eds., 2007).

but the ballpark cost estimates have broad enough support, and are so strikingly cheap, that SRM is pushed straight into the limelight and becomes seductive for any policy maker concerned about economics.²¹ Second, sulphur techniques are relatively familiar because they correspond quite closely to what happens when volcanos erupt.²² It is well known that major eruptions cause temporary decreases in global temperature as a result of the sulphurous particles they pump into the upper atmosphere; so sulphur techniques can be given an aura of naturalness, even safety, by presenting them as comparable to volcanos.²³ Such techniques just add a bit more to the stratosphere of the same substance that goes there naturally. This is, perhaps, less alarming than the more radical or innovative SRM techniques and, in some eyes, less risky.²⁴ Third, there appears to be a fairly broad agreement that sulphur techniques would actually work — partly based on that volcano experience.²⁵ Thus it can be argued that there is no false promise being made here, but a concrete, practical, and affordable proposal.

However, the particular weakness of SRMs in general, including sulphur techniques, is that they may have nasty, unexpected, or even catastrophic side effects — perhaps reducing precipitation, changing monsoon circulation, causing rainforest contraction, or changing ocean currents such as the El Nino.²⁶ In particular, there may be local and regional variations in the effects so that global climate improvement may mask local environmental disaster, such as desertification or changes in wildlife or plant populations which may impact agriculture and access to food.²⁷ Because SRM does not reduce the amount of CO₂ in the atmosphere, it also does not solve the nontemperature problems that this creates, notably acidification of the oceans.²⁸ In general, SRM creates a new atmospheric situation, with high CO₂ but relatively low temperature, with who-knows-what consequences. It can be argued that global warming itself shows that we should not play such experimental atmospheric games.

In the midst of such a sea of proposals, and arguments and counterarguments, the challenge is to decide how to assess them rationally. Geoengineering promises too much to be dismissed out of hand, but raises too many risks to be casually embraced. Some form of balancing of risks and benefits is inevitable. The particular challenges for this balancing are twofold. First, there are many uncertainties involved, making it difficult to quantify or even determine what is to be balanced. Second, there are very different issues and interests at stake, from the narrowly environmental to the social and economic. Comparing these may seem like comparing apples and pears. Nevertheless, the following sections suggest that a risk-benefit analysis is both possible and inevitable.

21. See *infra* pp. 118-20.

22. Wigley, *supra* note 10, at 452-53.

23. Crutzen, *supra* note 3, at 212.

24. Wigley, *supra* note 10, at 452-53.

25. See *supra* notes 16-18 and accompanying text.

26. ROYAL SOC'Y, *supra* note 1, at 36; Bradley, *supra* note 19, at 4; Brewer, *supra* note 3, at 9915; Alan Robock et al., *A Test for Geoengineering*, 327 SCIENCE 530, 530 (2010); David G. Victor, *On the Regulation of Geoengineering*, 24 OXFORD REV. ECON. POL'Y 322, 323 (2008).

27. See *supra* note 26 and accompanying text.

28. Alan Robock, *20 Reasons Why Geoengineering May Be a Bad Idea*, BULL. ATOMIC SCIENTISTS, May/June 2008, at 14, 15; Wigley, *supra* note 10, at 452-53.

RISK-BENEFIT ANALYSIS OF GEOENGINEERING

Where complex policy choices have to be made it is commonplace to engage in cost-benefit analysis. The costs and benefits associated with each possible choice are established, and then typically they are quantified, usually in financial terms. This enables them to be compared, so that it can be seen which choice is the most advantageous.

Where the outcomes of particular choices are uncertain a technique called risk-benefit analysis is commonly used.²⁹ This is similar, except that for each possible cost and benefit a risk is assigned, indicating how likely that outcome is. In straightforward cases the quantified value of the cost or benefit is then multiplied by the chance that the outcome will occur, and the results of this can be added up to indicate the net advantage or disadvantage of the course of action.³⁰

It has been argued that such risk-benefit analysis is not appropriate for issues like geoengineering, which involve both indeterminacy and severe risks.³¹ First, there are too many "unknown unknowns." Climate engineering is likely to cause at least some problems which are completely unexpected and so cannot be identified *a priori*. We do not then possess all the information necessary for such an analysis.³² Second, even where we have some idea of the kinds of risks in issue, the state of scientific knowledge is such that we cannot assign probabilities with any precision or accuracy. Assignment would be essentially arbitrary. This makes meaningful quantification of costs and benefits and their comparison impossible.³³ Third, it is sometimes argued that some outcomes are so unspeakably awful that they should not even be accepted as possibilities.³⁴ They should be excluded in advance, rather than costed and weighed. This argument is often used where human life is concerned: should one person be killed if it would save ten elsewhere? A mere mathematics of life is repugnant to many. Similarly, the risk of catastrophic climate side effects, with inevitably devastating social, human, and moral consequences, is not something to be coolly quantified, but to be prohibited, it may be claimed.³⁵

None of these arguments are entirely convincing. While it is true that the risks of geoengineering cannot be accurately assessed, or even identified, it may be that this is equally true of not geoengineering. In that case the unknown variables recur on both sides of the equation and may be eliminated. If there is no reason to think that more unknown unknowns are associated with geoengineering than with continued CO₂ emission, or that the inaccuracy of risk assessment is greater on one side than on the other, then the two can be compared on the basis of the remaining factors. Thus the

29. RICHARD WILSON & EDMUND A.C. CROUCH, *RISK-BENEFIT ANALYSIS* 8 (2d ed. 2001).

30. Andreas Klinke & Ortwin Renn, *A New Approach to Risk Evaluation and Management: Risk-Based, Precaution-Based, and Discourse-Based Strategies*, 22 *RISK ANALYSIS* 1071, 1076 (2002).

31. *Id.* at 1072.

32. H. Damon Matthews & Ken Caldeira, *Transient Climate-Carbon Simulations of Planetary Geoengineering*, 104 *PROC. NAT'L ACAD. SCI.* 9949, 9952 (2007); H. Damon Matthews & Sarah E. Turner, *Of Mongooses and Mitigation: Ecological Analogues to Geoengineering*, *ENVTL. RES. LETTERS*, Oct.-Dec. 2009, at 1, 7; Robock et al., *supra* note 26, at 531; Victor, *supra* note 26, at 329.

33. Klinke & Renn, *supra* note 30, at 1073-74.

34. HAMPSHIRE, *supra* note 5, at 16-18; Gardiner, *supra* note 5, at 299-300; Kelman, *supra* note 5, at 33.

35. Gardiner, *supra* note 5, at 16-18.

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extent to which inaccuracy, indeterminacy, and uncertainty are problems for a risk-benefit analysis depends on what geoengineering is to be compared with, the subject of discussion below.

Something similar is true of the catastrophic side-effects argument. If this means that SRM geoengineering cannot even be considered, then it may also mean that CO₂ emission also cannot be considered. It therefore leads quickly and simply to the conclusion that the only path legitimately open to consideration is CO₂ reduction combined with nonthreatening CDR techniques. This is understandable, but the question is whether it is useful. If, as a matter of fact, the reality may diverge from this ideal, it is suggested that policy makers should have some way of considering the pros and cons of the various diverging paths.

The argument against risk-benefit analysis of geoengineering, or of climate change in general, is fundamentally a fear of over-quantification and over-simplification. The temptation in cost-benefit and risk-benefit analysis is to overvalue factors which are easy to identify and measure, and so which tend to be concrete, economic, and immediate, and to undervalue factors which may be subtle, hard to measure, or long term. Social, human, and ethical effects, and effects which are complex, are easy to ignore or push aside in the desire to produce hard results.

However, this is not inherent in the balancing process. Risk-benefit analysis may be done in an amateurish and clunky way, but it can also be done in a more complete and sophisticated way. Fear of a simplistic process is not a convincing argument against attempts to weigh risks and benefits more intelligently.

Nor does such weighing rely on all factors being quantified. It may be hard to say how we can compare an apparently nonquantifiable risk — the chance that society becomes harder and more exploitative — against a simpler one — the chance of reduced rainfall in location X. Yet we engage in such balancing processes every day when we purchase things which we think will bring us pleasure. The economists' idea of revealed preferences enables us to put a value on our pleasures and sufferings, by asking how much we would pay to avoid or achieve certain results.³⁶ The fact that assessing the risks and benefits of geoengineering, or alternative policy paths, will result in a mix of quantified and nonquantified factors does not exclude the possibility of decision making based on weighing options.

Indeed, the fundamental argument in favour of risk-benefit analysis in this context is that it is the only nonarbitrary form of decision making. Whenever choices are to be made there is no alternative than to weigh the pros and cons. A taboo on a given outcome is simply an extremely high (infinite) quantification of a certain cost. There is no risk-benefit analysis problem with this, although such weightings should be assigned with care to ensure that they represent an authentically strong preference, rather than a symbolic gesture or an aversion to engaging with reality. An *a priori* decision to exclude geoengineering as a policy option, or even to stop researching it, is merely an ad hoc risk-benefit analysis in which the conclusion has been quickly reached by assuming that

36. Paul A. Samuelson, *Consumption Theory in Terms of Revealed Preference*, 15 *ECONOMICA* 243, 243 (1948); P. A. Samuelson, *A Note on the Pure Theory of Consumer's Behaviour*, 5 *ECONOMICA* 61, 62-71 (1938).

nothing could counterbalance some of the apparent costs. That may ultimately be true, but it will be suggested below that upon careful analysis of the alternatives, on the basis of current science, it is not self-evident.

Excluding a thorough risk-benefit analysis on the basis of the conclusions of an ad hoc balancing process is therefore difficult to justify. The only serious argument for doing so is that the risk-benefit analysis process is itself dangerous because it will tend to be done so badly that it will lead to wrongful results: We shouldn't think any more about this because we'll only get ourselves in a muddle. That argument is not ridiculous. The fear that risk-benefit analysis will be distorted by technocrats and number crunchers into a simplistic process is not without foundation, as the significant scholarship on the dangers of over-technocracy tells us.³⁷ However, it seems unlikely that the opponents of risk-benefit analysis are sufficiently powerful to prevent others from engaging in it. Geoengineering will, despite protests, be considered and its risks and benefits weighed. In that case, it is suggested, let us try and do the process well.

THE PROCESS OF RISK-BENEFIT ANALYSIS

The essence of risk-benefit analysis is that it assists in choosing between alternatives. The costs and benefits of a policy pathway can only be meaningfully assessed by comparison with some alternative scenario. There is thus no sense in applying risk-benefit analysis to geoengineering techniques alone. It must also be applied to other possible scenarios, in order to see which are preferable. The first step is therefore to decide on the alternatives — the policy choices or paths with which geoengineering must be compared.

A standard risk-benefit approach is to consider the most probable or plausible alternative path only.³⁸ This enables one-on-one comparison and makes the process easier. However, it is clearly an approximation, since other possible paths are ignored.³⁹ The issues involved here are too important to permit such a rough-and-ready approach. Thus as well as assessing the chances of certain events given a certain policy path, we also need to assess the chances of those paths.

A simple approach would be to consider three paths:

- (1) SRM geoengineering;
- (2) CO₂ emission reduction, through some combination of reduced use and CDR techniques; and
- (3) Continued CO₂ emissions at current, near current, or even greater levels.

These three options correspond broadly to (1) a choice for active geoengineering, (2) a safe and responsible move to a low-emissions world, and (3) a failure to engage

37. E.g., Denis Smith & Steve Tombs, *Of Course It's Safe, Trust Me!*, in RISK MANAGEMENT AND SOCIETY 1, 8-9 (Eve Coles et al. eds., 2000); Mihail Kritikos, *Traditional Risk Analysis and Releases of GMOs into the European Union: Space for Non-Scientific Factors?*, 44 EUR. L. REV. 405 (2009); Myanna Lahsen, *Technocracy, Democracy, and U.S. Climate Politics: The Need for Demarcations*, 30 SCL., TECH., & HUM. VALUES 137, 143 (2005).

38. Sven Ove Hansson, *Economic (Ir)rationality in Risk Analysis*, 22 ECON. & PHIL. 231, 231-32 (2006).

39. *Id.* at 238.

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with the issue leading to business as usual and increased global warming.

Either one could compare path one with path two and then path one with path three to produce independent estimates of the relative benefits of each path. Alternatively, one could assign probabilities to paths two and three, use these to produce a compound cost-benefit result for these two options, and then compare this with path one. This would amount to comparing geoengineering with “not geoengineering.”⁴⁰

Ultimately, one would hope for more complex models, in which intermediate paths can be weighed and considered, but the sketch above gives an idea of the kind of comparisons which have to be made. What is immediately apparent is that the desirability of geoengineering is highly dependent upon the relative chances of paths two and three.⁴¹ If it were known that, if it came to the brink, the world would collectively act to reduce CO₂ to safe levels, this would make geoengineering far less attractive. If it were known that there would be a collective policy failure until it was too late, geoengineering would become correspondingly more attractive. As well as the scientific and climatic factors, one of the most important areas for research is therefore political. There is an urgent need for consideration of the likely global governance outcomes and likely CO₂ emissions if SRM is excluded.

Such predictive political research is daunting at the best of times. What complicates it in this context is reflexivity. A common argument against geoengineering is that it distracts, or offers false hope, and therefore reduces the chance of emissions reductions.⁴² Considering path one may therefore make path three more likely than path two. The very fact of academic and policy engagement with the possibilities of path one may tilt the balance of the alternative scenarios in favour of path three, making path one more desirable. Geoengineering discussion may therefore be self-fulfilling. By contrast, excluding geoengineering in advance would make states more likely to agree to reductions and to follow path two. Hence, it is argued, the interest in the best possible solution, path two, is served by refusing to consider geoengineering right now.

Despite this not-implausible argument, it is unlikely to be sufficient to stifle discussion.⁴³ Thus, if the aim is to produce real-world analysis, it is probably necessary to consider the chances of paths two and three in a world in which path one is a possibility on the table, albeit that this may seem like “cheating” to geoengineering opponents. The “moral hazard” argument against geoengineering, or even geoengineering research, as it is often called, is likely to be simply beside the point.

In any case, the argument is presumptuous. By resisting exploration of climate management on the basis that it may inhibit emissions reduction, it assumes that the latter is preferable to the former, but this is one of the questions which the currently available evidence does not in fact decide. In particular, it seems far from impossible that policy packages will ultimately include a mix of reduced emissions, climate intervention,

40. *Id.*

41. Crutzen, *supra* note 3, at 216-17.

42. David R. Morrow et al., *Toward Ethical Norms and Institutions for Climate Engineering Research*, ENVTL. RES. LETTERS, Oct.-Dec. 2009, at 1, 3; Robock, *supra* note 28, at 18; Stephen H. Schneider, *Earth Systems: Engineering and Management*, 409 NATURE 417, 417-18 (2001); Virgoe, *supra* note 3, at 104.

43. Edward A. Parson, *Reflections on Air Capture: The Political Economy of Active Intervention in the Global Environment*, 74 CLIMATIC CHANGE 5, 13 (2006).

and acceptance of warming. One does not need to believe that geoengineering may be a complete solution, or a best option, to believe that it may be a desirable element of a realistically achievable total policy package.

In addition, the moral hazard argument raises one very real danger: that if global warming reaches a point where geoengineering clearly is desirable the political and research base will not be there. Such things take time. It is not particularly precautionary to defer thinking about emergency measures until the emergency is here.

A further complicating factor is that the nature of the reflexivity between the various paths is not uncontested. It has been argued that the possibility of geoengineering actually makes emissions reductions more likely. Because the cheap and easy SRM techniques could be done unilaterally but might have unpleasant side effects, if a single state were to consider using SRM this might be perceived by others as threatening and actually motivate them to agree to more conservative emissions reductions or CDR techniques.⁴⁴ Global discussion of path one might frighten everybody into path two. Alternatively, it has also been argued that the use or possibility of geoengineering might galvanize the public or policy makers and motivate them to mitigate emissions.⁴⁵ There really is an urgent need for more research on whether these arguments work.

The process described above provides a framework within which costs, risks, and benefits can be compared. The next step is then to clarify and actually weigh those costs, risks, and benefits. This is where research is still at a relatively early stage, and it is the progress of that research which will make rational, evidence-based decision making possible. However, a qualitative survey of the kinds of pros and cons which may be involved is possible, and that is the aim of the following section. Such a survey provides more clarity about the nature of the balancing involved and the problems it may raise.

THE RISKS AND BENEFITS OF GEOENGINEERING AND ITS ALTERNATIVES

This part of the article outlines the factors needing to be considered in making a risk-benefit analysis of geoengineering and its alternatives. It focuses on sulphur-based SRM measures, since these are currently attracting particular attention for their apparent low costs and high effectiveness. The costs, risks, and benefits associated with geoengineering and its alternatives are grouped into four types: environmental factors, economic factors, governance factors, and social factors.

Environmental Consequences

Sulphur-based or particulate-based SRM is likely to lower temperature effectively, but, as was discussed above, it will either not solve, or will introduce, other problems.⁴⁶ First, it does nothing about the acidification of the oceans which results from raised CO₂ levels and which may harm ocean life.⁴⁷ There are suggestions that it may be possible to

44. Sarah Polborn & Felix Tintelnot, *How Geoengineering May Encourage Carbon Dioxide Abatement* 1, 2 (Ctr. for Research on Int'l Fin. & Energy Security, Working Paper, 2009) available at <http://crifes.psu.edu/papers/polbornpaper.pdf>.

45. ROYAL SOC'Y, *supra* note 1, at 43; Matthews & Turner, *supra* note 32, at 5.

46. See *supra* text accompanying note 26.

47. See *supra* text accompanying note 24.

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address this acidification by other means, but research is not at a stage offering any certainty.⁴⁸ Second, SRM may have a negative effect on the ozone layer, leading to ozone depletion and subsequent problems for human, animal, and plant life.⁴⁹ As with acidification, there are suggestions that this problem may be manageable, but the current research provides no certainty.⁵⁰ Third, SRM promises considerable regional variations in its effects. Reduced global temperature averages may conceal not just local temperature differences but fail to mention other local climatic effects, notably reduced precipitation. The world, or at least many parts of it, might become cooler and drier, partly as a result of reduced evaporation as a consequence of reduced sunlight reaching the surface of the planet.⁵¹ This could of course impact agriculture, biodiversity, and lifestyle, as well as leading to migration and water conflicts of varying scales and severities.⁵²

All of these risks are significant, but seem assessable and not determinative. There may be ways of managing them, and none are of an order that would exclude consideration of SRM or further research. One would expect that in the coming years it would be possible to take a position with reasonable confidence on how serious they are and use this alongside the cooling effects of SRM and its cost to weigh its desirability.

However, other aspects of SRM are commonly regarded as problematic. One is that it has to be continuously maintained, whether it is by ongoing cloud enhancement or ongoing insertion of sulphur into the stratosphere.⁵³ If SRM was stopped the temperature could “rebound,” given that high CO₂ levels would be present, resulting in an extremely fast increase in temperature.⁵⁴ Not only would the good work of cooling be undone but the speed of the change could itself be destabilizing for ecosystems or climate systems so that the resulting warming could be even more catastrophic than if it had occurred more slowly.⁵⁵ An SRM approach therefore requires stable governance and a long-term commitment, and/or a well-thought-through exit strategy, such as gradually lowering CO₂ to the point where SRM can be gradually reduced.⁵⁶ The risk of rebound is clearly one to be taken seriously, but it seems unlikely that states, having established an SRM system, would behave suicidally and suddenly walk away from it. Even in the event that some states did, the relative cheapness and ease of SRM would mean that other states could maintain the process. Therefore, it seems that the risk raised here is not so much of rebound actually occurring but of states being trapped in an ongoing governance process. The specter is raised of a governance cost. It is considered below whether forcing states to engage in long-term, multilateral environmental governance is really such a negative effect.⁵⁷

48. ROYAL SOC'Y, *supra* note 1, at 36; Lenton & Vaughan, *supra* note 1, at 5556.

49. Crutzen, *supra* note 3, at 213-14.

50. ROYAL SOC'Y, *supra* note 1, at 31.

51. Robock et al., *supra* note 26; Victor, *supra* note 26, at 326-28.

52. Robock et al., *supra* note 26; Victor, *supra* note 26, at 326-28.

53. Schneider, *supra* note 1, at 3857.

54. Matthews & Caldeira, *supra* note 32, at 9952.

55. *Id.*

56. ROYAL SOC'Y, *supra* note 1, at 56; Schneider, *supra* note 1, at 3857.

57. *See infra* pp. 120-22.

Fear of governance is part of another, closely related, criticism of SRM: that it sucks the globe into a never-ending chain of measures.⁵⁸ It creates side effects which in turn require management, and this management will no doubt create new side effects and so on, until we are engaged in a sort of endless damage limitation exercise.

While plausible, it is suggested that the way to deal with this is just to try to identify and quantify the specific problems and assess them. The presentation above suggests that the total harm is greater than the sum of the parts, as if the fact of one measure making others necessary and creating an ever-broadening environmental management process is in itself a significant harm. There are certainly arguments to be made about this (considered below), but it is far from obviously a good point, and the approach taken is not that taken in other analogous, scientific circumstances. Geoengineering is, for example, analogous to a drug in development which promises effective treatment for some threatening disease but with the likelihood of unpleasant or serious side effects.⁵⁹ Does the public then dismiss the drug or sneer at it? On the contrary, the fact of a possibility of treatment is seen as exciting and hopeful, and new research is hurriedly commissioned to see if the side effects can be managed or reduced. In general, we accept that every solution brings new problems, and we seek to understand and minimize these problems, and ultimately to make rational assessments of whether the cure is in fact worse than the disease. There seems no reason to consider the chain of consequences argument as a particularly persuasive downside to geoengineering, above and beyond what those actual consequences may be.⁶⁰

The real, and more serious, fear underlying the chain of consequences argument is that geoengineering will have unintended consequences. The single most powerful argument against it is that we simply do not know what its consequences will be, and some of them may be entirely unexpected and far worse than we had imagined.⁶¹ Without this argument SRM would almost certainly enjoy far more support. However, climate change itself gives us a hint of the scale of the harm that atmospheric meddling can cause and provides for many a conclusive argument that geoengineering is far too dangerous except as an alternative to imminent catastrophe.

It is, of course, hard to say anything definite about the scale or extent of unknown risks. An interesting attempt has been made by Damon Matthews and Sarah Turner, who have drawn a comparison that has been made with other areas where humankind has intervened in complex biological systems with good intentions.⁶² The authors conclude that often the consequences were unexpected, complicated, and worse than anticipated and that, despite a chain of remedial reactions, the well-intentioned initial measures did end up making everything much worse. They concede that risk-assessment is more sophisticated now than in the time of the interventions they consider, but nevertheless

58. James Lovelock, *A Geophysicist's Thoughts on Geoengineering*, 366 PHIL. TRANSACTIONS ROYAL SOC'Y 3883 (2008); Schneider, *supra* note 1, at 3857; Victor, *supra* note 26, at 328.

59. Victor, *supra* note 26, at 326-27 (comparing geoengineering with the "cocktail" of drugs used to combat HIV infection).

60. Russell Powell et al., *The Ethics of Geoengineering* 3 (James Martin Geoengineering Ethics Working Grp., Working Paper), available at <http://www.practicaethicsnews.com/files/geoengineering-final.pdf>.

61. Schneider, *supra* note 1, at 3855; Victor, *supra* note 26, at 328.

62. Matthews & Turner, *supra* note 32. See also Victor, *supra* note 26, at 328.

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conclude that there is evidence of a human tendency towards hubris — that when faced with exciting and innovative solutions, people overestimate benefits and the chances of success and underestimate risks and the chances of harm.⁶³ Particularly where a severe consequence has a relatively low probability we may tend to put it out of our minds.⁶⁴ We have a tendency to want to believe what is easy and convenient and to neglect counter-evidence. Hence, even if the little we know about geoengineering and climate may suggest positive outcomes, we should consider the larger picture of a species that consistently overestimates its capacity to manage the environment and stay well away from such a complex and vital system as the atmosphere. This is particularly so because we are not talking about contained intervention in a defined area but about creating global changes which have the capacity to cause global harm, potentially catastrophic.⁶⁵ We may not understand the climate well enough to predict all the outcomes of geoengineering, but research into human behavior provides little reason not to expect unpleasant surprises if we allow optimism, good intentions, and just a dash of scientific understanding to be our policy guides.

This precautionary approach is thought provoking. It has pessimistic and antiscientific undertones which make it no less valid but will determine the groups to whom it appeals.⁶⁶ However, it is less useful than first appears as a guide to action. The reason is that all the arguments are equally true of not geoengineering. We may be a hubristic species prone to leaping clumsily into the dark, but the real question facing us is not whether to leap into darkness, but in which direction. All policy options take us into the unknown. The perception that leaping in darkness is dangerous does not help us here.

This is most obviously true of continued CO₂ emission via the use of carbon fuels.⁶⁷ Global warming also promises unexpected consequences of unknowable severity. There is no reason at all to think that the consequences of SRM would be more surprising or more serious. Thus if SRM and business as usual are being compared the “unknown unknowns” argument appears on both sides of the equation and simply drops away. It is, however frightening the prospect, a policy irrelevance at most and may actually support SRM, since it is commonly felt that this would result in more predictable and safer climate outcomes than warming.

Where the precautionary argument appears to carry weight is if the alternative to SRM is reduced emissions. A precondition for dismissing geoengineering as dangerous on the basis of unintended consequences is therefore sufficient confidence that emissions will be reduced. Otherwise we simply trade the chance of side effects in a cool world for side effects in a hot world. Where geoengineering is dismissed in public discourse as too dangerous this is often from the perspective that emissions reduction “must” occur. However, mature policy entails recognising that sometimes what “must” happen does

63. See BENT FLYVBJERG ET AL., *MEGAPROJECTS AND RISK: AN ANATOMY OF AMBITION* (2003).

64. See Hansson, *supra* note 38, at 232.

65. Matthews & Turner, *supra* note 32, at 7.

66. See generally MIKE HULME, *WHY WE DISAGREE ABOUT CLIMATE CHANGE: UNDERSTANDING CONTROVERSY, INACTION AND OPPORTUNITY* (2009); Adam Corner & Nick Pidgeon, *Geoengineering the Climate: The Social and Ethical Implications*, 52 ENV'T 24 (2010).

67. Powell et al., *supra* note 60, at 3.

not. Blind adherence to the impossibility of anything other than emissions reductions does not represent environmental commitment so much as ideological commitment; it indicates a readiness to sacrifice actual environmental interests to policy purity. To coin a cliché: the best is the enemy of the good.

There is a striking irony here. Dismissing geoengineering as a dangerous gamble is itself gambling that, if geoengineering is dismissed, emissions reduction will in fact prevail. Since the consequences of losing that gamble are in fact just as bad, probably worse, than the consequences of geoengineering, it is hard to see how research and policy engagement with geoengineering can be in any sense more irresponsible than avoiding it.

Put in a rather crude and simplified way: if geoengineering is declared taboo, we have a chance of catastrophe (global warming $C(GWt)$) and a chance of safety (emissions reduction $S(ERt)$). If geoengineering is on the table as an option, we have two chances of catastrophe (geoengineering goes wrong $C(G)$, or global warming $C(GW)$) and two chances of safety (emissions reduction $S(ER)$, or geoengineering actually works without disaster $S(G)$). For a taboo on geoengineering to be advantageous, from this perspective, it would have to reduce the chance of emissions reduction by more than the chance that geoengineering would work. That is to say $S(ER) + S(G) < S(ERt)$. Such a standpoint seems speculative in the extreme for the reasons discussed earlier.⁶⁸ More sociological research might support this position, but it might also demolish it; for example, if it appears that the threat of geoengineering in fact motivates emissions reduction.

In any case, there may be (unknown) risks in CO₂ reduction, counterintuitive though this is. Is it as unequivocally harmless as is assumed? Like raising CO₂ levels or adding sulphur particles, reducing CO₂ levels also represents an active intervention in the atmosphere. Indeed, given that CO₂ has been climbing for some time, one could argue that even stabilizing CO₂ levels represents an active intervention against the background status quo. In fact, that very idea of “status quo” has been lost sight of some time ago, and all options, including reduction in CO₂ emissions, represent some kind of climate manipulation.⁶⁹ On this abstract level there is no type-difference between emitting less CO₂, emitting more, or adding sulphur. The difference is between the risks associated with each kind of climate engineering, and the assumption is that emitting less is by far the safest, even riskless.

There is no intention here to claim that this view is wrong but merely to ask whether it is entirely supported by current evidence. On the one hand, it is certainly the case that the atmosphere seems to have enjoyed considerable stability before we began overfilling it with CO₂, which would suggest that if we can return to that situation the climatic stability may return too. However, we cannot entirely return to that situation. The earth has changed — fewer forests, fewer fish, more urban area, other man-made chemicals in the atmosphere — and will continue to change under the influence of growing and developing population. Climate is not purely a product of CO₂ levels but of

68. See *supra* text accompanying notes 42-43.

69. Gareth Davies, *Law and Policy Issues of Unilateral Geoengineering*, in 2 SELECT PROCEEDINGS OF THE EUROPEAN SOCIETY OF INTERNATIONAL LAW 628 (Hélène Ruiz Fabri et al. eds., 2010); Parson, *supra* note 43, at 9.

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the interaction of various factors, so that returning CO₂ to previous levels without returning the physical global environment to that previous situation in fact represents a new environmental scenario. It is possible to make the same claims about unknown risks as for geoengineering.

The disturbing fact is that CO₂ reduction is also taking us into the unknown. It may cool effectively, but other aspects of climate, from precipitation to wind and ocean current patterns, might not be the same post-cooling, either because of the changed earth or because the changes in climate we have already experienced are not simply reversible; there are many complex systems whereby reversing one's steps does not take one back to the beginning.

Nevertheless, it does seem overwhelmingly likely on the basis of knowledge so far that reducing CO₂ would be a more predictable and safer pathway than SRM. At least, this is the only conclusion which can be drawn by the nonscientist from the existing scholarship. However, applying the arguments about complexity and tipping points which scholarship musters against CO₂ emission to its reduction suggests that the difference is less absolute than may sometimes be claimed. That suggests we should investigate it carefully. The comparison between SRM and CO₂ reduction merits thorough research.

Indeed, the author admits to the same fear of sounding anti-CO₂ reduction which manifestly infects much writing about climate change and geoengineering in particular. Many articles consist of careful scientific discussion of geoengineering followed by anxious assertions that of course CO₂ reduction is best, while this is not in fact the unambiguous conclusion of the presented research. No one wants to seem to be on the side of the nutcases, and those who believe in global warming have an understandable fear of dividing their camp and becoming vulnerable to the skeptics or the forces of darkness. Yet, summoning up my courage, if one were to think rigorously about this issue, one should be skeptical of CO₂ reduction as an unproblematic pathway to restoring past climatic conditions.

The theory of second best, familiar to economists, describes a commonsensical but nevertheless true and important rule: that the action which achieves the best result under perfect circumstances may not be the one which achieves the best result under imperfect circumstances.⁷⁰ Indeed, where systems are complex even a slight change or imperfection in background circumstances may dramatically change the effects which different kinds of actions achieve. The optimal approach may become a disastrous approach as a result of apparently minor changes in circumstances. Of course, it may not.

The law of second best does not say that every circumstantial change does bring chaos to our ideas of best practice, just that it may. The only answer is to investigate carefully. However, given that it is such a well-known phenomenon of complex systems that small changes can have large effects, it would be rather amateur to assume that CO₂ reduction will simply take the climate back to where it was and to assume that it cannot have dramatically unexpected results. The risks of CO₂ reduction need to be assessed, and then we need to think whether we should also be concerned about unknown risks.

70. R.G. Lipsey & Kelvin Lancaster, *The General Theory of Second Best*, 24 REV. ECON. STUD. 11, 11-32 (1956), reprinted in READINGS IN SOCIAL WELFARE: THEORY AND POLICY 47 (Robert E. Kuenne ed., 2000).

This, of course, is an impossible question, but the best we can do is estimate whether we understand the system as a whole; and if investigating the effects of CO₂ reduction reveals that we do not, then we may have to stop regarding this approach as precautionary and view it as just another CDR geoengineering technique. A survey of the literature suggests that the safe and precautionary nature of CO₂ reduction is more often taken for granted than it is shown to be the case.

Economic consequences

The upfront costs of sulphur-based SRM have been put at somewhere in the order of tens of billions of dollars per year, as discussed above.⁷¹ These do not seem particularly speculative. There are concrete ideas of how sulphur insertion can be achieved, and, as a result, the general order of magnitude seems to enjoy a reasonable consensus. However, added to this cost should of course be the costs of mitigating side effects, which currently are a great unknown and about which it should be commented that the evidence shows a human tendency to underestimate the costs of ambitious and exciting projects.⁷² A number of authors are deeply skeptical of the headline figures for SRM, considering them as little more than “startup costs.”⁷³ It is the price tag on the consequences that we really need to see. Nevertheless, it is not inconceivable that these consequences can be managed and priced. Early research provides some hope that acidification of the oceans and ozone reduction can be combated,⁷⁴ and it is far from inconceivable that a climate-preserving SRM package would be relatively affordable.⁷⁵

The costs of conventional mitigation are harder to assess. The most authoritative estimate so far, the Stern report, estimated something between four hundred billion and a trillion dollars per year.⁷⁶ In contrast, the International Panel on Climate Change appears to prefer a lower figure of around fifty billion dollars per year, but this does not appear to be the price of full mitigation and does not enjoy the same support (yet?) as the Stern figure.⁷⁷ Other research supports the lower estimates however, partly on the grounds that mitigation would entail the development of new technologies, particularly in energy generation, which would have positive economic and social spin-offs.⁷⁸ A seductive and understandable view is to see conventional mitigation not so much as a cost but as a catalyst for transition to a cleaner, more energy-abundant, and ultimately better-off planet.

However, similar arguments can be made about geoengineering. Embracing climate management would entail not only new science and technology but new governance mechanisms, the possibility to maintain optimal climatic conditions, and

71. See *supra* text accompanying note 19.

72. FLYVBJERG, *supra* note 63; Gardiner, *supra* note 5; EDWARD W. MERROW ET AL., A REVIEW OF COST ESTIMATION IN NEW TECHNOLOGIES: IMPLICATIONS FOR ENERGY PROCESS PLANTS (1979); Victor, *supra* note 26.

73. See generally Gardiner, *supra* note 5; Victor, *supra* note 26.

74. Lenton & Vaughan, *supra* note 1, at 5556.

75. Keith, *supra* note 4, at 495-96; Barrett, *supra* note 20, at 49; Carlin, *supra* note 1, at 1490.

76. STERN, *supra* note 20.

77. Barker & Bashmakov, *supra* note 20.

78. Ottmar Edenhofer et al., *Mitigation Strategies and Costs of Climate Protection: The Effects of ETC in the Hybrid Model MIND*, ENERGY J. (SPECIAL ISSUE) 207 (2006).

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perhaps, ultimately, to prevent or contain many natural disasters. Whether or not this picture is attractive to all, geoengineering is equally a path that entails long-term, socio-economic consequences, which perhaps make its up-front costs rather a sideshow.

Thus the long-term economic comparison between mitigation and geoengineering is a difficult one, with no clear winner. It may even be pointless. The two are not necessarily alternatives to each other, not least because carbon fuel resources are limited, so that alternative energy technology will probably be part of the future quite aside from the climatic imperative.

The comparison between the direct costs of SRM and conventional mitigation becomes, therefore, more central. This comparison cannot be properly made yet because too little is known about the side effects of SRM and there is too little certainty on the costs of conventional mitigation. However, it is worth noting that it is quite possible — if Stern and the Royal Society are right — that SRM is orders of magnitude cheaper than emissions reduction and that there is a difference of some hundreds of billions of dollars per year.

If so, this has to be taken seriously. The cost difference is not conclusive in any risk-benefit analysis, because SRM might have side effects which would make such a price look trivial, but these sums are of an order which could make a significant impact on world hunger, combating disease, or the availability of universal education, for example. It would take a rather insular rich-world perspective to consider these unimportant considerations in making a choice between reducing carbon fuel use and putting sulphur in the stratosphere. Even some side effects of SRM might be worth tolerating. How much acid rain is ending hunger worth?

Governance Consequences

Some forms of geoengineering, in particular SRM, are affordable enough to be carried out by a single state or even a wealthy individual or corporation.⁷⁹ Geoengineering is also, however, something that would seem to naturally call for international systems of governance and control.⁸⁰ Both possibilities raise risks.⁸¹

The unilateral exercise of geoengineering is something that might come about as a result of frustration with failure to avoid climate change by other means or in an attempt to avoid emissions reductions. It might be pursued by a state who is particularly suffering from warming or by a state that is particularly under fire for its contribution to warming and wants to disarm that criticism by taking other measures.⁸² It might also be undertaken by groups of states, rather than single ones, a possibility that is perhaps more likely. If sufficient, or sufficiently powerful, states agree that geoengineering is

79. Davies, *supra* note 69; Victor, *supra* note 26, at 329-30; Virgoe, *supra* note 3, at 116.

80. Davies, *supra* note 69; Victor, *supra* note 26, at 329-30; Virgoe, *supra* note 3, at 116.

81. Richard B. Bilder, *The Role of Unilateral State Action in Preventing International Environmental Injury*, 14 VAND. J. TRANSNAT'L L. 51, 86 (1981); Daniel Bodansky, *The Legitimacy of International Governance: A Coming Challenge for International Environmental Law?*, 93 AM. J. INT'L L. 596, 598 (1999); Daniel Bodansky, *What's So Bad About Unilateral Action to Protect the Environment?*, 11 EUR. J. INT'L L. 339, 346 (2000); Laurence Boisson de Chazournes, *Unilateralism and Environmental Protection: Issues of Perception and Reality of Issues*, 11 EUR. J. INT'L L. 315, 332 (2000).

82. Parson, *supra* note 43, at 13.

advantageous, they may decide to override the objections of others.

The immediate problems of tortious liability for side effects and regional variations in effect are obvious and fundamentally similar to liability for causing climate change by CO₂ emission. It has been pointed out that, in either case, establishing causation may be very difficult.⁸³ While trends may be attributed to changing temperatures, it is not always easy to show that a particular event, such as a hurricane or flood, is sufficiently causally related to another atmospheric event or change.

However, the scale of the effects of geoengineering is such that tortious liability may be somewhat beside the point. The greater threat from unilateral action is of conflict between states, either directly caused by what is perceived to be hostile and harmful action or indirectly caused by the effects of the resulting climate change.⁸⁴ For example, local variation may cause regional precipitation reduction or ocean current changes which may lead to famine, poverty, and/or migration — all the classic ingredients for transnational problems and conflict. There seems little doubt that large-scale climate intervention can be dangerously destabilizing.

On a more conceptual level one may ask how the world should react to states or individuals who actually prefer warmer temperatures. It has been suggested that Canada and Russia, with their vast frozen hinterlands, have much to gain from global warming. This is no doubt very much open to debate, but would it be open to them in principle to challenge artificial cooling of the earth to pre-global-warming temperatures on the grounds that this cooling is causing loss of fertile land and harming their interests? Most geoengineering envisages a change from the status quo and so can be presented by victims as a harmful act, however fragile, temporary, and unnatural that status quo in fact is.

There is an understandable consensus that unilateral geoengineering is a potentially frightening scenario and that such decisions should be made, if at all, in the context of agreed multilateral mechanisms.⁸⁵ Yet the need for these is often seen as an undesirable side effect in itself.⁸⁶ As was discussed above, SRM cannot just be stopped once started and will create its own problems, so that the necessary climate governance institutions will acquire a life and momentum of their own, with all the usual democratic and functional problems associated with international institutions of this type.⁸⁷ Is this a road we want to go down? Is it desirable that any body, however expert or multilateral, should have its hand on the global thermostat, wielding thereby a power beyond comparison with almost any other — perhaps only possession of a nuclear arsenal is comparable, if less practically usable — and certainly beyond that ever wielded by institutions beyond

83. Michael G. Faure & André Nollkaemper, *International Liability as an Instrument to Prevent and Compensate for Climate Change*, 26A STAN. J. INT'L L. 123, 157 (2007); David A. Grossman, *Warming Up to a Not-So-Radical Idea: Tort-Based Climate Change Litigation*, 28 COLUM. J. ENVTL. L. 1, 22 (2003); Robock et al., *supra* note 26, at 531.

84. Gardiner, *supra* note 5, at 298; Schneider, *supra* note 1, at 3846; Victor, *supra* note 26, at 324.

85. Schneider, *supra* note 1, at 3846; Victor, *supra* note 26, at 325; Virgoe, *supra* note 3, at 112.

86. Victor, *supra* note 26, at 325.

87. *Id.* Cf. Thomas C. Schelling, *The Economic Diplomacy of Geoengineering*, 33 CLIMATIC CHANGE 303 (1996) (arguing that the governance issues surrounding geoengineering are not novel or particularly problematic but merely cost and burden allocation questions, with which the international community is familiar from its many collective ventures).

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the state?

These questions are real and need consideration. However, they are only half the story, and there is a notable absence in the literature of the other half. This half suggests that creating global climate governance institutions is not a necessary price but an actively good thing. It is an extra bonus of geoengineering, not a cost.

Such institutions amount to an acceptance of responsibility for human actions. Aside from global warming, humankind has the capacity to change and to harm the earth in various ways, and preventing such harm inevitably requires transnational action. Environmental issues are often held up as examples of where national borders are more of a help than a hindrance and where only global thinking makes sense. There is at least a good argument that the lack of a global environmental governance system is a rather frightening absence and that, from a strategic environmental point of view, any action which can help generate such institutions is to be welcomed, at least on these grounds. From this point of view, the fact that SRM entails a long-term commitment, and that all but the most suicidal state will recognize that once begun they cannot simply walk away, is an added strength. A decision to start SRM forces states to commit to collective long-term responsibility for sustaining the global environment. There may be other downsides, but that in itself looks rather like a plus.

What is urgently needed is political analysis of the dynamics of this process. What are the chances of unilateral action and the kinds of reactions which may be generated? What are the possibilities for multilateral cooperation, and how likely is it that this will lead to deep and responsible governance, or rather to dysfunctional stasis or the crushing of minority voices? Internationalising any issue brings possible benefits and risks, and there seems to be no safe default position here. The current state of law and governance is no guarantor of responsible environmental management. We are forced to try and assess the risks and benefits of the various possible paths.

Social Consequences

The way that geoengineering in particular may contribute to social change, values, and identity is likely to be complex. However, it is suggested that two risks stand out, and these risks are greatest precisely if geoengineering is effective and successful. One is that by making it okay to burn carbon fuels, and to have burned carbon fuels, we effectively let intensive carbon fuel users off the hook. Not only does this raise moral issues of punishment and responsibility but one wonders whether it sends a message to environmental wrongdoers which we may one day regret.⁸⁸ The other related risk is that we give a great boost to consumerism and an exploitative mentality, fueling a techno-trusting, gung-ho approach to the earth.⁸⁹ That might work this time, but will it always work? The arguments for avoiding harm, rather than remedying it, are broader than the specific context of climate change.

The first of these risks can be summarized by saying that the big downside of

88. See Dale Jamieson, *Ethics and Intentional Climate Change*, 33 CLIMATIC CHANGE 323 (1996); Jay Michaelson, *Geoengineering: A Climate Change Manhattan Project*, 17 STAN. ENVTL. L.J. 73, 132-34 (1998). See also Gardiner, *supra* note 5, at 295; Schneider, *supra* note 1, at 3847.

89. Corner & Pidgeon, *supra* note 66.

geoengineering is that it lets the bad guys get away with it. Those who burned too much without caring and ignored the claims that they were destroying the planet can turn round and say: ey, it turned out okay didn't it? What was all the fuss about?

The most immediate objection to this may be moral. In most criminal law systems, attempted murder is punished as seriously, or almost as seriously, as actual murder. If ignoring climate change and wasting carbon fuels is wrong because on current best evidence it is dangerous for the planet, then such action becomes no less wrong because the planet turns out to have been savable by other means, unless those burning the fuel knew or reasonably suspected that this would be the case. Will they claim that? Will they say that they always had faith that a solution would be found? Perhaps so, but the claim will have a distinct air of opportunism. Thus it does seem likely that a considerable group of people who are currently showing behaviour which may be argued to be wrongful, even despicable, will "get away with it."

This will be distressing for some, but may also raise concrete social risks: these people were prepared to destroy the earth for their own short-term interests. Is it really safe to rehabilitate them? What will they do next? There may be an analogy drawn with releasing an attempted murderer on the grounds that the attempt failed, although the weakness in the analogy is that the motives and sensibility of those overusing carbon fuels are far more complex and in many cases rest on incomplete information, genuinely different perspectives, and local social norms as much as on a thought-through choice for narrow self-interest at the expense of others. It may be unfair to characterize them as quasi-criminal, but, on the other hand, in some cases it may not.

A particularly painful aspect of this arises for those who link environmental causes with other political issues, notably social justice or anti-capitalism. Many environmentally committed people consider that protecting the environment is inexorably bound up with matters such as north-south justice, the dominance of trade and market values over other values, the capitalist economic system, patriarchy, materialism, and no doubt other things too. Destructive behaviour, on this view, is not to be viewed in isolation but to be seen in context and related to its diverse causes. The threat to this world view comes because geoengineering, if successful, threatens to divorce the most important single environmental issue from this matrix.⁹⁰ The climate would have been threatened by the capitalist, oil-burning status quo, and then rescued by it too, or at least the threat would have gone away. There seems little doubt that a certain amount of resistance to geoengineering comes from this perspective, and is fueled by a political reluctance to concede that there might be a technical solution and that broader social and economic change might be, at least for this issue, an irrelevance.⁹¹ The loss of climate change as a very large stick with which to beat the establishment and as powerful evidence for the failure and corruption of that establishment, would certainly be a political setback for various groups, as well as a great gain for those with a vested interest in carbon, technology, and the status quo.⁹²

A political resistance to geoengineering is perhaps at its most convincing if one

90. Lal, *supra* note 4; Michaelson, *supra* note 88, at 135; Virgoe, *supra* note 3, at 105.

91. Corner & Pidgeon, *supra* note 66; Lal, *supra* note 4, at 520.

92. Corner & Pidgeon, *supra* note 66; Lal, *supra* note 4, at 520.

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thinks long term. It may be, hard though it is to imagine, that partly thanks to SRM (or other approaches) global warming will go the way of the ozone layer and smog and be solved by primarily technical interventions, becoming a historical issue even within decades. The question is what conclusion we should draw from this. Will we have had a warning and a lucky escape, and, having learned a lesson, will we rush to gratefully change our distinctly overconsuming ways to prevent being brought to the brink of disaster again over some other issue — the seas perhaps, or biodiversity? Or will most people conclude that environmental issues are always solvable by science, that there is no conflict between consumption and sustainability, and that we should get on and enjoy our lives and leave policy makers and their technocrats to deal with the consequences? Geoengineering could lead to a more complacent world, and by turning the threat of climate doom into an unrealized cry of wolf turn us into easy prey for future real environmental wolves which may cross our path. It would be an irony if saving the planet from warming paved the way for ecological doom to come. If SRM were to work in an acceptable way it would initially appear, given the threats and costs of alternatives, to be a dramatic stroke of good fortune. But how much do we trust ourselves to remain responsible in the face of such luck?

CONCLUSION

The global climate is at risk but so too is its economy and the living standards of its population. We may devastate all three or find ways of keeping them all healthy. The basic toolbox consists of geoengineering, CO₂ emission reduction, and carbon fuels, which all offer something good and something bad, costs and benefits. The challenge is to find which combination of these tools takes us in which direction, and the only thing which can be concluded with certainty on the basis of existing literature is that not all the information is in. We could eliminate geoengineering *a priori* and make decision making easier, but it would not be better policy. The risks and benefits which our actions and inactions entail are rather too large to make ad hoc decisions not founded on research. SRM in particular offers exciting possibilities for guilt-free carbon. Those possibilities may come to nothing, as so many exciting early research results do, but it is very hard to accept the conclusion that they should not be explored.

Such exploration might make geoengineering look attractive in two kinds of circumstances. One is where there is a failure to control emissions, and climate catastrophe looms. Here geoengineering may be a tool of last resort, a little scary, but nevertheless preferable to excessive global warming. This view is common in the literature. The other, more controversial, scenario is where risk-benefit analysis reveals geoengineering to be preferable, at least to some extent, to emissions reductions, because it offers lower costs at acceptable risk. Whether we can evaluate if this is the case depends on the extent to which these risks can be understood, but, most importantly, it also depends on an honest analysis of the costs of emissions reduction. If these are examined in terms of their impact on quality of life for the inhabitants of the planet, then the policy balancing process will become less banal, more complicated, but more worthwhile. Public authorities manipulate and regulate many aspects of public space; for example, via criminal law, social policy, and public health policy. The climate may

ultimately be just another addition to the repertoire of phenomena that are managed and controlled in the name of the collective good.

The heart of the resistance to geoengineering, however, is fear of the unknown. It may have consequences outside our models and beyond our nightmares. It is portrayed as an irresponsible gamble. Yet so too is burning carbon fuels, and so too would be declaring geoengineering taboo and deferring policy engagement or serious research. That would be a gamble that we will reduce emissions on time or that we can, if necessary, develop SRM in a hurry. These seem forms of blind optimism as cavalier and as dangerous as any which a cautious excitement about SRM entails.